8. COMPARISON OF OPTIONS

Earlier chapters of this report examined the GHG emissions from (1) raw materials acquisition and manufacturing (and forest carbon sequestration for paper products) and (2) waste management. In other words, the earlier chapters analyzed the two separate components of a complete life cycle analysis; the first part of the cycle being manufacturing, the second, waste management.[114] This chapter combines information from the earlier chapters to present a picture of the full life cycle GHG emissions associated with manufacturing, and then managing as waste, each of the materials considered in this analysis.

This chapter compares the life cycle GHG emissions for the five municipal solid waste (MSW) management options analyzed in this report (source reduction, recycling, composting, combustion, and landfilling), for each of the eight manufactured materials considered. (These materials are newspaper, office paper, corrugated boxes, aluminum cans, steel cans, and three types of plastic · LDPE, HDPE, and PET.) In addition, this chapter presents the GHG emissions from waste management for composting, combusting, or landfilling food scraps, yard trimmings, and mixed MSW (a full life cycle analysis for food scraps and yard trimmings is not appropriate because neither is manufactured; for mixed MSW · a composite of dozens of manufactured materials · developing a weighted average GHG emission rate is beyond the scope of this project.)

Using the estimates contained in this chapter of the full life cycle GHG emissions from (1) raw materials acquisition and manufacturing, and (2) waste management, one can compare any waste management option, for a given material, to any other waste management option. In this chapter we have provided an exhibit that compares each of four waste management options · source reduction, recycling, composting, and combustion · to landfilling (which is currently the most commonly used waste management option).

Our results show that source reduction has lower GHG emissions than all other options for all eight of the manufactured materials considered, if one assumes that source reduction will displace the use of virgin inputs. After source reduction, recycling has the next lowest GHG emissions. If one assumes that source reduction displaces the current mix of virgin and recycled inputs to manufacturing, recycling results in greater GHG reductions than source reduction for aluminum cans. Composting of food scraps and yard trimmings has GHG emissions in the same range as combustion and landfilling. Finally, comparing landfilling and combustion, landfilling has lower GHG emissions than combustion for newspaper and plastics; combustion has lower GHG emissions than landfilling for office paper and corrugated cardboard, as well as steel cans (since steel is recovered for recycling at most combustors); and emissions are similar for aluminum cans, food scraps, yard trimmings, and mixed MSW.

[114] The one exception is Chapter 4, on source reduction, which for the sake of clarity showed both (1) the GHG emissions from the manufacturing stage (i.e., zero, except for credits for forest carbon sequestration for paper products) and (2) the waste management GHGs (i.e., zero, because the material was not produced).

8.1 FULL LIFE CYCLE GREENHOUSE GAS EMISSIONS FOR EACH WASTE MANAGEMENT OPTION

This section presents the full life cycle GHG emissions for each waste management option, for each material considered. These emissions are shown in five exhibits that recapitulate the GHG emissions and sinks analyzed in detail in earlier chapters.

Exhibit 8-1 shows the life cycle GHG reductions associated with source reduction. In brief, the exhibit shows that source reduction of paper products results in GHG reductions (due to forest carbon sequestration), whereas source reduction of other materials results in no GHG emissions. This same exhibit was presented earlier in this report as Exhibit 4-1.

Exhibit 8-2 shows the life cycle GHG emissions associated with manufacturing and then recycling each of the materials considered. The values in the first column of the exhibit show the GHG emissions associated with the initial manufacture of each material, using the current mix of virgin and recycled inputs. The next four columns show the GHG reductions associated with using recycled inputs in place of virgin inputs when the material is remanufactured. The final column, which simply sums the others, shows the overall life cycle GHG implications of manufacturing and then recycling each material. The net carbon values for paper products are negative, primarily due to the forest carbon sequestration benefits of recycling. The net carbon value for aluminum is also negative, because the GHG emissions avoided by displacing 100 percent virgin inputs in the remanufacturing stage are larger than the GHG emissions from manufacturing using the current mix of virgin and recycled inputs. The net carbon values for steel cans and plastics are positive, indicating that manufacturing and then recycling the products results in net GHG emissions.

Exhibit 8-3 presents the life cycle GHG emissions from manufacturing and then combusting each of the materials considered. As the exhibit shows, manufacturing and then combusting each material results in net GHG emissions for nearly all of the manufactured materials. For food scraps and yard trimmings, the GHG emissions are slightly negative.

Exhibit 8-4 shows the GHG emissions from manufacturing and then landfilling each material. The final column shows the net GHG emissions from landfilling.

We have not provided an exhibit for composting. As described in Chapter 5, we performed a bounding analysis and concluded that GHG emissions from composting are zero or close to zero.

8.2 COMPARISONS OF THE WASTE MANAGEMENT OPTIONS

The full life cycle GHG emissions for each waste management option and each material are compared in Exhibit 8-5. As the exhibit shows, when the full life cycle, including manufacturing, is considered, source reduction dominates all other options (i.e., it has lower GHG emissions than any other option on a ton-per-ton basis) for all materials except aluminum cans. For aluminum cans, recycling has lower GHG emissions than source reduction only because the recycling value in this exhibit assumes that increased recycling results in displacement of virgin inputs, whereas the source reduction value assumes that source reduction results in displacement of the current mix of virgin and recycled inputs. If source reduction were assumed to displace virgin inputs, it would have lower GHG emissions than recycling in both cases.

Exhibit 8-1
Greenhouse Gas Emissions for Source Reduction
(MTCE/Ton of Material Source Reduced)

Material	**GHG Emissions from Raw Materials Acquisition and Manufacturing**	**Change in Forest Carbon Storage (Minus sign indicates incremental carbon storage)**		**Net GHGs**		
		Source Reduction Displaces Current Mix of Virgin and Recycled Inputs	Source Reduction Displaces Virgin Inputs	Waste Management GHGs	Source reduction Displaces Current Mix of Virgin and Recycled Inputs	Source Reduction Displaces Virgin Inputs
Newspaper	0.00	-0.48	-0.73	0.00	-0.48	-0.73
Office Paper	0.00	-0.53	-0.73	0.00	-0.53	-0.73
Corrugated Cardboard	0.00	-0.44	-0.73	0.00	-0.44	-0.73
Aluminum Cans	0.00	0.00	0.00	0.00	0.00	0.00
Steel Cans	0.00	0.00	0.00	0.00	0.00	0.00
HDPE	0.00	0.00	0.00	0.00	0.00	0.00
LDPE	0.00	0.00	0.00	0.00	0.00	0.00
PET	0.00	0.00	0.00	0.00	0.00	0.00

Exhibit 8-2
Recycling of Post-Consumer Material
(GHG Emissions in MTCE/Ton)

Material	Manufacturing GHG (Current Mix of Inputs)	Recycled Input Credit* Process Energy GHG	Recycled Input Credit* Trans. Energy GHG	Recycled Input Credit* Process Non-Energy GHG	Forest Carbon Sequestration	Net Carbon (Post-Consumer)
Newspaper	0.49	-0.14	0.01	0.00	-0.73	-0.37
Office Paper	0.53	-0.08	-0.01	0.00	-0.73	-0.29
Corrugated Cardboard	0.40	0.03	0.00	0.00	-0.73	-0.30
Aluminum Cans	2.96	-2.66	-0.07	-1.24	0.00	-1.01
Steel Cans	0.87	-0.57	-0.01	0.00	0.00	0.30
HDPE	0.72	-0.31	-0.02	-0.06	0.00	0.34
LDPE	0.87	-0.44	-0.01	-0.06	0.00	0.36
PET	0.98	-0.58	-0.02	-0.03	0.00	0.35
Food Scraps	NA	NA	NA	NA	NA	NA
Yard Trimmings	NA	NA	NA	NA	NA	NA
Mixed MSW	NA	NA	NA	NA	NA	NA

*Material that is recycled post-consumer is then substituted for virgin inputs in the production of new products. This credit represents the difference in emissions that results from using recycled inputs rather than virgin inputs. It accounts for loss rates in collection, processing, and remanufacturing. Recycling credit is based on weighted average of closed and open loop recycling for office paper and corrugated cardboard. However, all other estimates are only for the products themselves.

Exhibit 8-3
Combustion of Post-Consumer Material
(GHG Emissions in MTCE/Ton)

Material	Manufacturing GHG (Current Mix)	Transportation to Combustion	CO_2 from Combustion	N_2O from Combustion	Avoided Utility GHG	Avoided GHG: Steel Recovery	Net Carbon (Post-Consumer)
Newspaper	0.49	0.01	0.00	0.01	-0.11	0.00	0.40
Office Paper	0.53	0.01	0.00	0.01	-0.09	0.00	0.46
Corrugated Cardboard	0.40	0.01	0.00	0.01	-0.10	0.00	0.32
Aluminum Cans	2.96	0.01	0.00	0.00	0.00	0.00	2.97
Steel Cans	0.87	0.01	0.00	0.00	0.00	-0.42	0.47
HDPE	0.72	0.01	0.75	0.01	-0.26	0.00	1.22
LDPE	0.87	0.01	0.75	0.01	-0.26	0.00	1.38
PET	0.98	0.01	0.51	0.01	-0.13	0.00	1.38
Food Waste	NA	0.01	0.00	0.01	-0.03	0.00	-0.01 *
Yard Waste	NA	0.01	0.00	0.01	-0.04	0.00	-0.02 *
Mixed MSW	NA	0.01	0.10	0.01	-0.07	-0.01	0.04 *

* Excludes manufacturing GHG emissions.

Exhibit 8-4
Landfilling of Post-Consumer Material
(GHG Emissions in MTCE/Ton)

Material	Manufacturing GHG (Current Mix of Inputs)	Transportation to Landfill	Net Landfill CH_4	Landfill Carbon Sequestration	Net Carbon (Post-Consumer)
Newspaper	0.49	0.01	0.13	0.34	0.28
Office Paper	0.53	0.01	0.58	0.04	1.09
Corrugated Cardboard	0.40	0.01	0.26	0.23	0.44
Aluminum Cans	2.96	0.01	0.00	0.00	2.97
Steel Cans	0.87	0.01	0.00	0.00	0.88
HDPE	0.72	0.01	0.00	0.00	0.73
LDPE	0.87	0.01	0.00	0.00	0.88
PET	0.98	0.01	0.00	0.00	0.99
Food Scrap	NA	0.01	0.16	0.08	0.09 *
Yard Trimmings	NA	0.01	0.09	0.17	-0.07 *
Mixed MSW	NA	0.01	0.13	0.14	0.00 *

* Excludes manufacturing GHG emissions.

Exhibit 8-5
Greenhouse Gas Emissions from Source Reduction and MSW Management Options
(Assuming Initial Production Using the Current Mix of Virgin and Recycled Inputs)
(MTCE/Ton)

Material	Net Source Reduction Emissions	Net Recycling Emissions*	Net Composting Emissions**	Net Combustion Emissions*	Net Landfilling Emissions*
Newspaper	-0.48	-0.37	NA	0.40	0.28
Office Paper	-0.53	-0.29	NA	0.46	1.09
Corrugated Cardboard	-0.44	-0.30	NA	0.32	0.44
Aluminum Cans	0.00	-1.01	NA	2.97	2.97
Steel Cans	0.00	0.30	NA	0.47	0.88
HDPE	0.00	0.34	NA	1.22	0.73
LDPE	0.00	0.36	NA	1.38	0.88
PET	0.00	0.35	NA	1.38	0.99
Food Scraps	0.00	NA	0.00	-0.01	0.09
Yard Trimmings	0.00	NA	0.00	-0.02	-0.07
Mixed MSW	0.00	NA	NA	0.04	0.00

*Includes emissions from the initial production of the material being managed, except for food waste, yard waste, and mixed MSW.

**There is considerable uncertainty in our estimate of net GHG emissions from composting; the values of zero are plausible values based on assumptions and a bounding analysis.

After source reduction, Exhibit 8-5 shows that recycling has the next lowest GHG emissions. Recycling has lower GHG emissions than combustion or landfilling for all eight of the manufactured materials analyzed in this study.

Between combustion and landfilling, the strategy with the next lowest GHG emissions differs for different materials. Combustion has lower GHG emissions than landfilling for office paper, corrugated cardboard, and steel cans, because office paper and corrugated cardboard generate a substantial amount of methane when landfilled, and steel is recovered for recycling at most MSW combustors. Landfilling has lower GHG emissions than combustion for plastics and newspaper, because combustion of plastic results in substantial nonbiogenic CO_2 emissions, and landfilling of newspaper results in substantial carbon sequestration. The net GHG emissions from combustion and landfilling are similar (given the range of uncertainty in the values developed in this analysis) for aluminum cans. Composting is a management option for food scraps and yard trimmings; the net GHG emissions from composting, combusting, or landfilling these materials are similar, given the uncertainty in the analysis.

The ordering of these options is affected by (1) the GHG inventory accounting methods, which do not count CO_2 emissions from sustainable biogenic sources, but do count emissions from sources such as plastics, and (2) a series of assumptions on sequestration, future use of methane recovery systems, recovery system efficiency, ferrous metals recovery, and avoided utility fossil fuels. On a site-specific basis, the ordering of results between a combustor and a landfill could be different from the ordering provided here, which is based on national average results.

The full life cycle GHG emissions for each of the first four waste management strategies -- source reduction, recycling, composting, and combustion -- are compared to the GHG emissions from landfilling in Exhibit 8-6. This exhibit shows the GHG values for each of the first four management strategies, minus the GHG values for landfilling. This exhibit is provided because landfilling is often viewed as the baseline waste management strategy. With this exhibit, one may easily compare the GHG emissions from other waste management options to the GHG emissions from landfilling.

* * * * *

We close with a final note about the limitations of these GHG emission estimates, and their potential uses. We based our analysis on what we believed to be the best available data; where necessary, we made assumptions that we believe are reasonable. However, the accuracy of the estimates is limited by the assumptions made, and by limitations in the data sources. We have discussed these limitations throughout this report.

We anticipate four potential applications for the GHG emission estimates provided here. First, organizations that are interested in quantifying GHG emission reductions due to source reduction or recycling may use these estimates for that purpose; EPA may soon use these estimates as the basis for developing guidance for voluntary reporting of GHG reductions, as authorized by Congress in Section 1605(b) of the Energy Policy Act of 1992. Second, the estimates may be useful for evaluation of MSW management options on a national, regional, state, or local basis. Third, EPA plans to use the estimates to evaluate its progress in reducing US GHG emissions by promoting source reduction and recycling through programs such as WasteWi$e and Unit-Based Pricing, as part of the US Climate Change Action Plan. Finally, this report may also assist other countries involved in developing GHG emissions estimates for their solid waste streams.

Exhibit 8-6
Greenhouse Gas Emissions of MSW Management Options Compared to Landfilling
(MTCE/Ton)

Material	Source Reduction Net Carbon Minus Landfilling Net Carbon		Recycling Net Carbon Minus Landfilling Net Carbon	Composting Net Carbon Minus Landfilling Net Carbon	Combustion Net Carbon Minus Landfilling Net Carbon
	Current Mix of Inputs	100% Virgin Inputs			
Newspaper	-0.76	-1.07	-0.65	NA	0.12
Office Paper	-1.62	-1.85	-1.38	NA	-0.63
Corrugated Cardboard	-0.89	-1.15	-0.74	NA	-0.12
Aluminum Cans	-2.97	-5.52	-3.98	NA	0.00
Steel Cans	-0.88	-1.13	-0.58	NA	-0.42
HDPE	-0.73	-0.73	-0.39	NA	0.50
LDPE	-0.88	-0.92	-0.52	NA	0.50
PET	-0.99	-1.19	-0.64	NA	0.38
Food Scrap	NA	NA	NA	-0.09	-0.10
Yard Trimmings	NA	NA	NA	0.07	0.05
Mixed MSW	NA	NA	NA	NA	0.04